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Scaling Properties of Fluctuation Results from the PHENIX Experiment at RHIC

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Scaling Properties of Fluctuation Results from the PHENIX Experiment at RHIC

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Abstract. The PHENIX Experiment at the Relativistic Heavy Ion Collider has made measurements of event-by-event fluctuations in the charged particle multiplicity as a function of collision energy, centrality, collision species, and transverse momentum in several heavy ion collision systems. It is observed that the fluctuations in terms of σ^2/μ^2 exhibit a universal power-law scaling as a function of $N_{participants}$ that is independent of the transverse momentum range of the measurement.

PACS. 25.75.-q Relativistic heavy-ion collisions – 24.60.Ky Fluctuation phenomena

1 Introduction

The topic of event-by-event fluctuations of the inclusive charged particle multiplicity in relativistic heavy ion collisions has been revived by the observation of non-monotonic behavior in the scaled variance as a function of system size at SPS energies [1]. The scaled variance is defined as σ^2/μ, where σ^2 represents the variance of the multiplicity distribution in a given centrality bin, and μ is the mean of the distribution. For reference, the scaled variance of a Poisson distribution is 1.0, independent of N. PHENIX has studied the behavior of inclusive charged particle multiplicity fluctuations as a function of centrality and transverse momentum in $\sqrt{s_{NN}} = 62$ GeV and 200 GeV Au+Au and Cu+Cu collisions in order to investigate whether the non-monotonic behavior persists at RHIC energies.

Details about the PHENIX experimental configuration can be found elsewhere [2]. All of the measurements described here utilized the PHENIX central arm detectors. The maximum PHENIX acceptance of $|\eta| < 0.35$ in pseudorapidity and 180^o in azimuthal angle is considered small for event-by-event measurements. However, the event-by-event multiplicities are high enough in RHIC heavy ion collisions that PHENIX has a competitive sensitivity for the detection of many fluctuation signals. For example, a detailed examination of the PHENIX sensitivity to temperature fluctuations derived from the measurement of event-by-event mean p_T fluctuations is described in [3].

2 Data Analysis

It has been demonstrated that charged particle multiplicity fluctuation distributions in elementary and heavy ion collisions are well described by negative binomial distributions (NBD) [4]. The NBD of an integer m is defined by

$$P(m) = \frac{(m+k-1)!}{m!(k-1)!}\frac{(\mu/k)^m}{(1+\mu/k)^{m+k}} \tag{1}$$

where $P(m)$ is normalized for $0 \le m \le \infty$, $\mu \equiv < m >$. The NBD contains an additional parameter, k, when compared to a Poisson distribution. The NBD becomes a Poisson distribution in the limit $k \to \infty$. The variance and the mean of the NBD is related to k by $1/k = \sigma^2/\mu^2 - 1/\mu$. The PHENIX multiplicity distributions are well described by NBD fits for all species, centralities, and transverse momentum ranges. The data presented here are results of NBD fits of the multiplicity distributions, an example of which is shown in Fig. 1.

Each 5% wide centrality bin selects a range of impact parameters. This introduces a component to the multiplicity fluctuations that can be attributed to fluctuations in the geometry of the collision. It is desireable to estimate and remove this known source of fluctuations so that only fluctuations due to the dynamics of the collision remain. The contribution of geometrical fluctuations is estimated using the HIJING event generator [5], which well reproduces the mean multiplicity of RHIC collisions [6]. The estimate is performed by comparing fluctuations from events with a fixed impact parameter to fluctuations from events with a range of impact parameters covering the width of each centrality bin. The HIJING estimates are confirmed by comparing the HIJING fixed/ranged fluctuation ratios to measured 1%/5% bin width fluctuations. A 15% systematic error for this estimate is included in the errors shown.

By measuring the scaled variance in successively wider azimuthal ranges, a linear dependence on azimuthal acceptance is observed. In order to facilitate direct comparisons with other experiments, the multiplicity fluctuations quoted here have been linearly extrapolated to 2π acceptance by fitting the azimuthal dependance within the detector acceptance. Systematic errors due to the extrapolation have been included in the total errors shown.

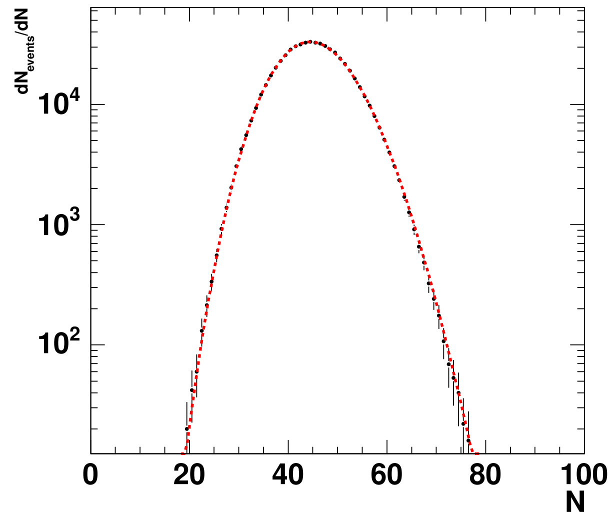

Fig. 1. PHENIX Preliminary. The event-by-event inclusive charged hadron multiplicity distribution for 0-5% central 200 GeV Au+Au collisions with transverse momentum in the range $0.2 < p_T < 2.0$ GeV/c. The dashed line is a Negative Binomial Distribution fit to the data.

3 Results

In the Grand Canonical Ensemble, the scaled variance of the particle number normalized by the mean can be directly related to the compressibility, $\sigma^2/\mu^2 = k_B(T/V)k_T$, where k_B is Boltzmann's constant, T is the system temperature, and V is its volume [7]. The multiplicity fluctuations in terms of σ^2/μ^2 are shown in Fig. 2 as a function of centrality for 200 and 62 GeV Au+Au and Cu+Cu collisions. In order to demonstrate their scaling properties as a function of centrality, each curve has been scaled uniformly as a function of centrality to best correspond to the 200 GeV Au+Au curve. The 62 GeV Au+Au, 200 GeV Cu+Cu, and 62 GeV Cu+Cu data have been scaled by factors of 0.75, 1.35, and 0.75, respectively. All four datasets exhibit identical scaling as a function of $N_{participants}$.

It is expected that the compressibility diverges as one approaches the critical point, and the rate of divergence is described by a power law, $k_T = A((T - T_C)/T_C)^{-\gamma}$, where T_C is the value of the temperature at the critical point, and γ is the critical exponent for isothermal compressibility [7]. For illustration, the dashed curve on Fig. 2 is a fit to the critical exponent power law function with $V \propto N_{participants}$, $T \propto N_{part}^{1/3}$, and $N_{part,c} \rightarrow 0$. With these assumptions, the critical exponent $\gamma = 1.09 \pm 0.06$. If QCD behaves like the 3-D Ising model, as suggested in [8], one expects $\gamma = 1.0$. Note that the onset of critical behavior is only one possible explanation for the observed scaling properties in the multiplicity distributions, and this interpretation is contingent on the assumption that the system temperature varies as a function of centrality.

Figures 3 and 4 show the multiplicity fluctuations as a function of centrality for different p_T ranges. In each case, the scaling properties remain unchanged. Hence the influence of p_T-dependent processes at higher p_T, such as hard scattering have little effect on the scaling properties. An analysis of 22 GeV Cu+Cu collisions in the PHENIX detector is currently underway in order to determine if the scaling properties persist at lower collision energy.

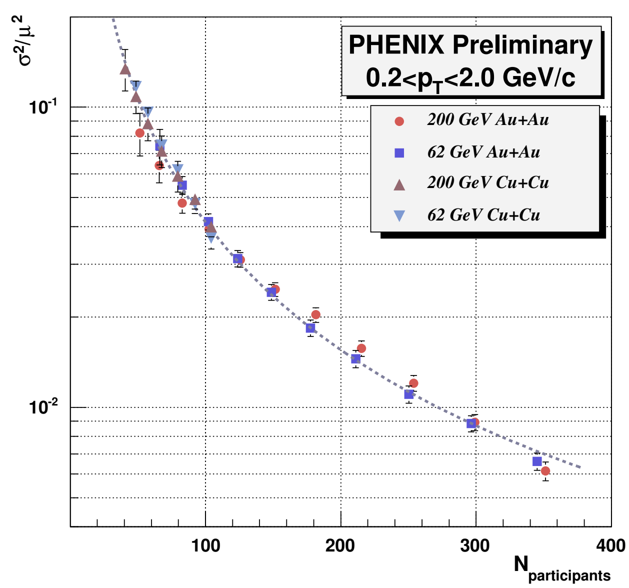

Fig. 2. Multiplicity fluctuations for inclusive charged hadrons in the transverse momentum range $0.2 < p_T < 2.0$ GeV/c in terms of σ^2/μ^2 as a function of $N_{participants}$ for 200 GeV Au+Au, 62 GeV Au+Au, 200 GeV Cu+Cu, and 62 GeV Cu+Cu collisions. The data have been scaled by factors of 1.0, 0.75, 1.35, and 0.75, respectively in order to emphasize the universal scaling of all species. The dashed curve is a power law fit as described in the text.

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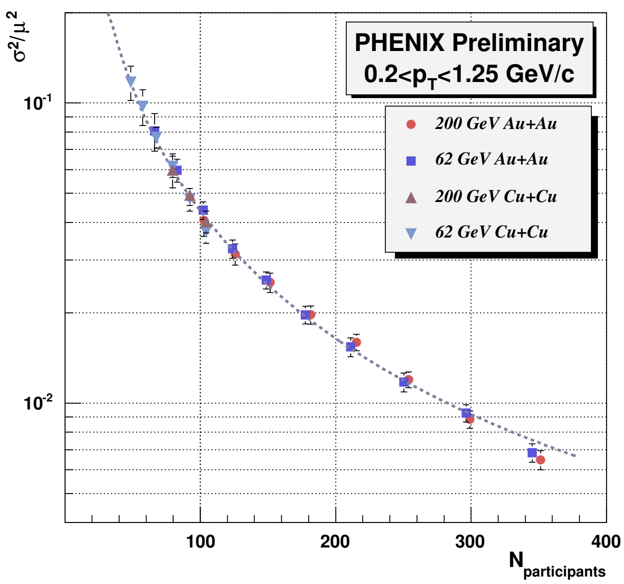

Fig. 3. Multiplicity fluctuations for inclusive charged hadrons in the transverse momentum range $0.2 < p_T < 1.25$ GeV/c in terms of σ^2/μ^2 as a function of $N_{participants}$ for 200 GeV Au+Au, 62 GeV Au+Au, 200 GeV Cu+Cu, and 62 GeV Cu+Cu collisions. The data have been scaled by factors of 1.0, 0.75, 1.35, and 0.75, respectively in order to emphasize the universal scaling of all species. The dashed curve is a power law fit as described in the text.

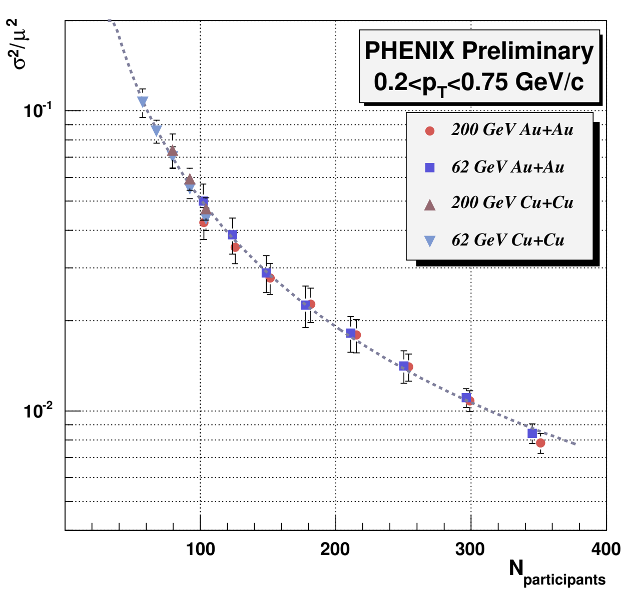

Fig. 4. Multiplicity fluctuations for inclusive charged hadrons in the transverse momentum range $0.2 < p_T < 0.75$ GeV/c in terms of σ^2/μ^2 as a function of $N_{participants}$ for 200 GeV Au+Au, 62 GeV Au+Au, 200 GeV Cu+Cu, and 62 GeV Cu+Cu collisions. The data have been scaled by factors of 1.0, 0.75, 1.35, and 0.75, respectively in order to emphasize the universal scaling of all species. The dashed curve is a power law fit as described in the text.

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